Chapter Two: Geography and General Information

Contents

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This chapter begins by describing the property and ownership status for the uplands of the Sale 87 area. This is followed by a review of the oil and gas exploration and leasing history and a general description of the petroleum potential of the region, concluding with the current leasing status of the sale. The physical characteristics of the region are then described.

A. Property and Ownership description of the Sale 87 Area

1. Property Description

The Sale 87 area consists of uplands located just south of the Beaufort Sea coast, between the National Petroleum Reserve, Alaska (NPRA), and the Arctic National Wildlife Refuge (ANWR) with the Umiat baseline as its southern boundary (see Figure 1.1 and Plate I). This sale area is completely onshore.

The sale area includes the coastal plain of the North Slope of the Brook Range between the Staines and Canning rivers on the east and the Colville River on the west. This region is slightly smaller than the state of Massachusetts, encompassing more than 5 million acres of coastal lowlands, north-flowing braided rivers and streams, lakes, and gently rolling hills and valleys. The southern boundary forms the east-west Umiat baseline located at about 69 degrees, 23 minutes north latitude where ground elevation varies between 500 and 1200 feet above sea level. Elevation throughout the sale area is a key factor in the distribution of plants and animals as described in Chapter Three (AEIDC, 1975:35).

Prominent geographic features include the White Hills and Franklin Bluffs. The Sale 87 also includes portions of numerous rivers, including the Colville, Miluveach, Kachemach, Itkillik, Anaktuvuk, Chandler, Ugnuravik, Sakonowyak, Kuparuk, Toolik, Putuligayuk, Sagavanirktok, Kadleroshilik, Ivishak, Shaviovik, Kavik, Staines, and Canning.

The entire Sale 87 area is within the North Slope Borough (NSB). This home rule borough, incorporated in 1972, extends from the Chukchi Sea to the Canadian border. The borough has the powers of taxation, land management and zoning, and is responsible for providing borough communities with public works, utilities, education, health, and other public services. Following the Sagavanirktok River to the south, the first 60 miles of the Trans-Alaska Pipeline bisects the sale area. The sale area includes lands in the vicinity of the city of Nuiqsut on the Nechelik Channel of the Colville River, and the industrial community of Deadhorse at Prudhoe Bay. Nuiqsut residents rely heavily on the sale area for subsistence resources. Other NSB residents from Kaktovik, Barrow, and possibly Anaktuvuk Pass may travel to the sale area for subsistence

2. Ownership

The state of Alaska owns the surface of most of the Sale 87 area. Other surface estate owners within the general sale area boundary include Arctic Slope Regional Corporation (ASRC), City of Nuiqsut, the North Slope Borough, the federal government, and many Native allottees. The state of Alaska owns most of the subsurface estate beneath the sale area. Other parties with mineral interests in the sale area include ASRC and Kuukpik Corporation.

Ownership status for some lands offered for leasing has either not been determined or is disputed. The issue involves mineral interests and control over some uplands within the NPRA portion of the sale area. The disagreement is between ASRC and Kuukpik Corporation, and involves a key property right to the use and development of the subsurface estate (See sub-section 1, “Subsurface Estate” below).

The Alaska Statehood Act allowed the state of Alaska to select from the federal public domain 102.5 million acres of land as an economic base for the new state. The Act also granted to Alaska the right to all minerals underlying these selections and specifically required the state to retain this mineral interest when conveying interests in the surface estate. ANCSA, passed by Congress in 1971, allowed newly created Regional Native Corporations to select and obtain from the federal domain lands including the surface and subsurface estates within native corporation boundaries as an economic base. It also allowed for Native Village corporations and individual Native Alaskans to receive surface estate interests in land for their economic benefit. The surface estate of the uplands in the Sale 87 area fall into one of three ownership categories: land owned by the state of Alaska, land owned by ASRC, the Kuukpik Village Corporation (Nuiqsut), and land owned by Native Allottees.

a. Arctic Slope Regional Corporation Agreement

The subsurface estate within the portion of Sale 87 located within the Colville River Delta is jointly owned by the state and ASRC, the Regional Native Corporation for the North Slope. The joint ownership is the result of an agreement between the state and ASRC which was signed December 17, 1991, and approved by the legislature and became effective on May 27, 1992.

The agreement settled a long-running legal dispute concerning North Slope mineral ownership near Nuiqsut and Point Lay resulting from a 1974 agreement in which ASRC and the state agreed to exchange lands near Nuiqsut and Point Lay. Under the 1991 settlement, the state and ASRC agree to jointly own undivided interests in certain minerals (including oil and gas) in the mineral estate of disputed lands. The settlement also grants the state the executive right to hold oil and gas lease sales jointly for itself and ASRC.

If such lands are leased, the state and ASRC separately administer the lease with respect to its own undivided interest in the subsurface (the lessee must obtain a permit or approval from both the state and ASRC). The two parties have what is essentially an identical but separate relationship with the lessee with respect to the same mineral estate. Although such mineral cotenancies (possession of a unit of property by two or more persons) are unusual in Alaska, this is a frequent occurrence in other states, like Texas, where land ownership is more complicated. The agreement involves only the mineral estate; it does not change the surface ownership. The surface of the uplands within the agreement area near Nuiqsut is owned by the village corporation for Nuiqsut, Kuukpik Corporation, and by individual Native allotment holders. The subsurface estate beneath the tide and submerged lands, and bed of the Colville River within the sale area are also jointly owned by the state and ASRC.

Under the settlement agreement, the state does not give up any of its duties to the public imposed by law. The state still must determine whether a sale would be in the best interests of the state, and must follow relevant substantive and procedural requirements for leasing and for permitting subsequent exploration, development and production. The state retains all rights under state law to ensure that development activity on leased tracts complies with laws governing natural resource management and protection.

i. Subsurface Estate

Portions of the Sale 87 area are located within NPRA, and may also be subject to a 1987 land selection consent agreement between ASRC and the Kuukpik Corporation (Nuiqsut village). In that agreement these parties consented and agreed as follows:

(1) Kuukpik hereby gives its concurrence for ASRC to exercise its option under 1431(o) of ANILCA to acquire the ASRC Subsurface, but Kuukpik expressly conditions its concurrence in such acquisition of the ASRC Subsurface by reserving the right to consent to any Exploration and Development Activities that ASRC, its successors and assigns, may engage in from time to time with respect to the ASRC Subsurface.

(2) ASRC agrees that it will not engage in any Exploration and Development Activities with respect to the ASRC Subsurface without first obtaining the consent referred to in paragraph 1 of this agreement.

ASRC received title to these lands subject to this agreement. The state of Alaska received its undivided interest to the subsurface estate beneath these lands from ASRC in 1992, 1993, and 1994. The

state's title and leases issued on these lands are, therefore, also subject to the 1987 ASRC-Kuukpik Agreement.

ii. Surface Estate

With the exception of the bed of the Colville River, which is owned by the state, the surface estate of the uplands within the Colville River Delta portion of the Sale 87 area falls into one of two ownership categories: land owned by the Kuukpik Village Corporation (Nuiqsut), and land owned by Native Allottees. Kuukpik village land also breaks down into lands within and outside of NPRA.

Village Owned Lands outside of NPRA: The Alaska Native Claims Settlement Act, (ANCSA) allowed the Village of Nuiqsut (Kuukpik Corporation) to select and acquire lands in the Colville River Delta. Of Kuukpik's total entitlement of 115,000 acres (five townships), approximately 70,000 acres (three townships) could be selected outside of NPRA on lands that had been tentatively approved for conveyance to the state of Alaska. Under provisions of ANSCA, ASRC was allowed to acquire the subsurface estate beneath these lands. The 1974 Agreement between Kuukpik, ASRC, and the state of Alaska and the 1992 Settlement Agreement between ASRC and Kuukpik provided for the right of access to Kuukpik's surface. ASRC and the state of Alaska, their successors, assigns, and lessees were allowed to conduct oil and gas activities on Kuukpik's lands east of NPRA under the provisions of the 1992 Settlement Agreement, the lease, and, to the extent applicable, the requirements of AS 38.05.130.

Village Owned Lands inside of NPRA: In order to fully satisfy its land entitlement under ANCSA, Congress allowed Kuukpik to select certain lands within NPRA. Section 1431(o) of Alaska National Interest Lands Conservation Act, (ANILCA) allowed ASRC an option to acquire the subsurface estate beneath these village lands, provided that the village corporation concurred. In 1987, Kuukpik conditionally concurred to ASRC's acquisition of these subsurface interests. ASRC subsequently conveyed an undivided ownership interest to certain sections of these lands, located along the Nechelik Channel of the Colville River, to the state of Alaska under the 1991 Settlement Agreement between the state of Alaska and ASRC, (see above). In January 1996, ASRC initiated a lawsuit in federal court seeking a declaratory judgment that Kuukpik's consent rights under Section 1431(o) of ANILCA, the 1987 consent agreement and Section 14(f) of ANCSA do not constitute an absolute veto over exploration and development of ASRC's subsurface in NPRA, and that Kuukpik's consent may not be unreasonably withheld. The federal court has recently ruled that the lawsuit lacks federal jurisdiction and an order dismissing the case is forthcoming. No other litigation has been initiated and the dispute remains unsettled.

Should these jointly-owned lands within NPRA be offered and leased, the lessee may not exercise its access rights to the Kuukpik owned surface until the lessee makes provisions to compensate the landowner for all damages sustained by reason of entering upon the land as required by the lease, and, to the extent applicable, the requirements of AS 38.05.130 as required in the terms of the lease.

Copies of the 1974 Agreement, the 1991 Settlement Agreement between the state of Alaska and ASRC (which includes the 1987 ASRC-Kuukpik Agreement), and the 1992 Settlement Agreement between Kuukpik and ASRC will accompany the lease for any of the tracts to which the agreement applies. Copies of all agreements are available for review in the DNR's Public Information Center, Suite 200 in the Frontier Building, 3601 C Street, Anchorage Alaska, and are also available from DO&G on request.

Native Allotments: The surface estate to certain lands within the Sale 87 area are owned by Native allottees. Should these jointly-owned lands be offered and leased, rights to exploration and development of the oil and gas resources may not be exercised until the lessees make provisions to compensate the landowner for all damages sustained by reason of entering upon the land as required by the lease, and, to the extent applicable, the requirements of AS 38.05.130.

B. Exploration History of the North Slope and Beaufort Sea

Oil seeps have long been known to the Eskimos of the North Slope. Oil shale was used for fuel by early Eskimos according to archaeological evidence. Early traders reported seeps along the coast. The first geologic and topographic studies date back to 1901 and the first formal descriptions were recorded by the U.S.

Geological Survey in 1919. By 1921, prospecting permits were filed and in 1923 President Harding, established by executive order, the Naval Petroleum Reserve No. 4 (NPR-4). The NPR-4 is also known as National Petroleum Reserve-Alaska (NPRA). The Geological Survey conducted reconnaissance mapping from 1923 through 1926 and published the results in 1930 (Jamison et al, 1980:290; AEIDC, 1975:83).

The first exploration phase of NPR-4 ended in 1953. Between 1923 and 1953, the United States Navy drilled 37 test wells and found three oil accumulations and six gas accumulations within the reserve. Only two of these discoveries were considered sizable, namely Umiat, with an estimated 50 million barrels of recoverable oil, and Gubik, with an estimated 600 billion cubic feet of recoverable gas (Kornbrath, 1995:14). Gas from another of the discoveries, the small South Barrow gas field, is being produced today for local consumption at Barrow.

BLM opened North Slope lands for competitive bidding in 1958 when 16 thousand acres were offered in the area of the Gubik gas field. That same year BLM opened four million acres in an area south and southeast of NPR-4 for simultaneous filing and subsequent drawing. From 1962-1964 industry exploration programs expanded rapidly. During this period, Sinclair and British Petroleum drilled a total of seven unsuccessful wildcat wells in the arctic foothills (Jamison et al, 1980:292).

In 1964, under the Statehood Act, the state of Alaska selected some 80 townships across the northern tier of lands between the Colville and Canning Rivers and received tentative approvals on the 1.6 million acres from the federal government in October of the same year. In December 1964, the state held the 13th State Competitive Sale (the first on the North Slope) of leases covering 625,000 acres in the area east of the Colville River Delta. In July 1965, the state held the 14th State Competitive Sale which included the onshore area in the vicinity of Prudhoe Bay. In the 18th State Competitive Sale, held in January 1967, the offshore Prudhoe Bay tracts were offered and leased (Jamison et al, 1980:292-294).

Following the succession of dry holes in the arctic foothills, exploration shifted northward to the central coastal area. In 1965, the first holes drilled in the area immediately surrounding the Prudhoe Bay structure came up dry. In January 1967, in what was essentially a last ditch effort, a rig was moved to the Prudhoe Bay State No. 1 location near the mouth of the Sagavanirktok River. Twelve months later the discovery of the Prudhoe Bay oil field was announced (Jamison et al, 1980:290; AEIDC, 1975:83). Prudhoe Bay Field began production in 1977, and is currently estimated to have originally contained in excess of 12 billion barrels of economically recoverable oil (Figure 2.1), making it the largest oil field ever discovered in North America.

Following the Prudhoe Bay discovery, exploration activity increased dramatically. Thirty-three exploration wells were completed in 1969 as industry prepared for the Lease Sale 23 in September of that year. The state offered 413,000 acres along the Arctic coast between the Canning and Colville rivers and earned over $900 million in bonus bids on 164 tracts (Weimer, 1986:32; Jamison et al, 1980: 291). This was the last lease sale on the North Slope until the Joint Federal-State sale in December 1979. After the discovery of the Prudhoe Bay field and before the 1979 joint sale, over 100 exploratory wells were drilled on the North Slope, with 19 of those wells discovering oil or gas.

Figure 2.1 North Slope Fields and Announced Discoveries

In 1974, spurred by the OPEC oil embargo of 1973, the federal government began a second large exploration program in NPRA. Between 1974 and 1981, the United States Geological Survey (USGS), drilled a total of 27 test wells within NPRA. Other than two gas fields which are currently being produced to supply Barrow, no commercial deposits were discovered by this program. The two currently producing fields are the Walakpa Field, which contains an estimated 142 billion cubic feet of economically recoverable gas (Imm, per. comm., 1996), and the East Barrow Field, which contains an estimated 13 billion cubic feet of economically recoverable gas (Kornbrath, 1995;12). In 1980, Congress authorized competitive leasing within NPRA. From 1982-1984, four lease sales were held. A total of over 1.3 million acres were leased in the first three sales, generating over $84 million in total bonus bids. The final sale received no bids. Only one industry well was drilled on a lease acquired in these sales. This well, the ARCO Brontosaurus No. 1, was completed, plugged and abandoned in 1985.

The recent discovery of a giant oil field on the border of NPRA demonstrates that the area contains significant potential for the discovery of commercial oil and gas accumulations. In 1994, ARCO and partners discovered the Alpine accumulation on state and native corporation land along the Colville River and adjacent to the northeastern boundary of NPRA. In 1996, ARCO announced plans to develop the field which in the most recent estimate, contains 365 million barrels of economically recoverable oil (PNA, 1997). Development of this new oil field may generate renewed interest in the oil and gas potential of NPRA by both industry and government.

Since the 1979 Joint Sale, five federal lease sales have been held in the Beaufort Sea, and there have been 28 state lease sales offering both onshore and submerged Beaufort Sea acreage. To date 31 exploratory wells have been drilled in the federal waters of the Beaufort Sea resulting in five discoveries. These discoveries are Seal Island/Northstar, Kuvlum, Hammerhead, Sandpiper, and Tern Island/Liberty. To date, exploration wells drilled on North Slope state leases have resulted in 26 discoveries.

It is not surprising that many of these accumulations were found in the vicinity of Prudhoe Bay where the density of wells and seismic control is the highest and the geologic conditions optimal. At least eight of these post-Prudhoe Bay discoveries are currently producing oil because of the Prudhoe Bay infrastructure and their relatively close location to the Trans-Alaska Pipeline. Six of these, Lisburne, Kuparuk, Milne Point, Endicott, Niakuk, and Point McIntyre are major fields (Table 2.1). While initial production on the North Slope was from onshore areas, four fields produce at least some of their reserves from offshore areas, these fields are Endicott, Point McIntyre, Milne Point and Niakuk. In addition, British Petroleum has announced plans to produce the Northstar Field totally from offshore facilities (PNA, 1996).

Table 2.1 Major Producing Fields on the North Slope and in the Beaufort Sea

Field Name	Discovery Date	Production Began	Estimated Original Economically Recoverable Oil (MMBBL)	Estimated Original Economically Recoverable Gas (BCF)
Prudhoe Bay	1967	1977	12,219	28,203
Lisburne	1967	1981	145	362
Kuparuk	1969	1981	2,627	998
Milne Point	1969	1985	395	23
Endicott	1978	1987	622	987
Niakuk	1985	1994	66	34
Pt McIntyre	1988	1993	358	329

Source: ADNR 1996:22; Kornbrath 1995:17

Fields proposed for development, but not yet producing, include Badami, Northstar, Alpine, Liberty, Tarn, and West Sak. Conoco discovered the Badami field in 1991. It is located onshore near Mikkelsen Bay and has estimated economically recoverable reserves of 100 million bbl of oil (PIC, 1996). The Northstar field, owned by BP is estimated to contain 145 million barrels of economically recoverable oil, and is expected to come on-line around by 1999 (ADN, 1997b). The field is located offshore about six miles northwest of Prudhoe Bay.

In October of 1996, ARCO Alaska, Anadarko Petroleum Corporation, and Union Texas Petroleum Alaska Corporation, announced plans to develop the Alpine field in the Colville River area west of the Kuparuk oil field. Production is anticipated to begin by the year 2000 (PNA, 1997). The Liberty field is located on federal leases approximately five miles offshore in the Beaufort Sea, northwest of the Badami field. BP owns the lease and estimates there is 120 million barrels of recoverable oil. Production probably will begin in 2000 (ADN, 1997a). The Tarn prospect, owned jointly by ARCO and BP, is located southwest of Kuparuk and contains estimated proven and potential reserves of 50 million barrels. Production is expected to begin by late 1998 or early 1999 (Petroleum News Alaska, 1997)

Low-gravity oil sands (west Sak and Ugnu) were discovered in the Kuparuk River area in 1969. The West Sak alone contains an estimated 16 billion barrels of oil in-place and combined estimates for the West Sak and Ugnu are as high as 40 billion barrels in-place (Weimer, 1986:34). ARCO plans to start up production of the West Sak in 1997 and has estimated that the initial start-up area contains 300-500 million barrels of economically recoverable oil (ADN, 1996b). Similar low gravity sands are in production at the Milne Point Field where the combined production from 14 wells produces an average of about 3000 barrels of oil per day (PIA, 1995).

In 1997, BP and Chevron announced the discovery of the Sourdough field next to ANWR. Current information indicates Sourdough could contain 100 million barrels of recoverable oil. Further exploration is needed before determining whether to develop the field. The Sourdough project would require up to 35 miles of pipeline to link up with the Badami field to the west (Peninsula Clarion, 1997). ARCO drilled the Warthog prospect in the winter of 1997. The well is located in Camden Bay off the coast of ANWR. ARCO plugged and abandoned the well in December 1997. The results are confidential, and ARCO is currently evaluating its findings. (Lee, 1998).

Most recently, in February 1998, Arco, BP, and Exxon announced the discovery of two new oil accumulations, Sambucca and Midnight Sun, during the drilling of a Prudhoe Bay "satellite[1]" prospect. Test production from the discovery is planned for the first half of 1998.

C. Petroleum Potential

Sale 87 encompasses a vast and diverse area, which makes it difficult to assign an overall petroleum potential. ADNR has determined the petroleum potential to be low to moderate, with the potential generally increasing from south to north. Determining the petroleum potential involves the evaluation of several elements including geology, geophysics, and exploration history of the area.

For an accumulation of hydrocarbons to be recoverable, the geology must be favorable. This may depend on the presence of source and reservoir rock; the depth and time of burial; the presence of migration routes and geologic traps or reservoirs and the timing of fluid movements from source to trap. Source rocks are organic rich sediments, generally marine shales, which have been buried for a sufficient time, and with sufficient temperature and pressure to form hydrocarbons. As hydrocarbons are formed, they will naturally progress toward the surface if a migration route exists. An example of a migration route might be a permeable layer of rock in contact with the source layer, or fractures which penetrate organic rich sediments. A hydrocarbon reservoir is permeable rock that has been geologically sealed at the correct time to form a "trap." The presence of migration routes therefore affect the depth and location where oil or gas may pool and form an accumulation.

For a hydrocarbon accumulation to be economically producible the reservoir rock must have sufficient thickness, good porosity—number of pore spaces per volume, permeability—a rock's capacity for transmitting a fluid, and hydrocarbon volume or fill. The North Slope has all these favorable geologic conditions and, considering the exploration history of the area, the chances of finding undiscovered petroleum reservoirs are very good. Proximity to the collection, processing, and distribution network, however, directly affects the economic field size limit for an oil accumulation. Whereas accumulations in the order of a few tens of millions of barrels are considered economic to develop in the vicinity of the existing oil fields, accumulations need to be on the order of hundreds of millions of barrels to be considered economic in the

[1] A satellite is an oil and gas accumulation in and around a principal field such as Prudhoe Bay that is not part of the main reservoir.

more remote areas of Sale 87. Proximity and the resultant economic field size limit generally skews the petroleum potential to be low in the more remote southern portions of the sale area. It is anticipated that the remaining undiscovered accumulations are expected to be near or below the economic size limit. In light of these factors, ADNR considers the petroleum potential of the sale area to generally increase from low in the southern portion to moderate in parts of the northern portion.

The process of evaluating the oil and gas potential for state lease sale areas, such as the North Slope, involves the use of data, including seismic and well information which by law the division must keep confidential under AS 38.05.035(a)(9)(C). In order to protect these data, the division must generalize the assessment which is made public.

D. Physical Characteristics of the Sale 87 Area

1. Geology

Northern Alaska is made-up of three distinct geologic regions: the Brooks Range, the Arctic Foothills, and the Arctic Coastal Plain (Moore, et al., 1994). The sale area is located in the center of the Arctic Coastal Plain, and rock sequences with known petroleum potential underlie the entire region. The rocks under the sale area are exposed at the surface in the Brooks Range. Rock sequences are formed by geologic events and are often described in terms of the time period during which they were formed (see Table 2.2).

Table 2.2 Geologic Time and Formations

Eras	Periods	Epochs	Began Approximate Number of Years Ago
Cenozoic	Quaternary	Holocene (Recent)	10,000
		Pleistocene (Glacial)	1 million
	Tertiary	Pliocene	7 million
		Miocene	25 million
		Oligocene	40 million
		Eocene	60 million
		Paleocene	68-70 million
Mesozoic	Cretaceous	Upper & Lower	135 million
	Jurassic		180 million
	Triassic		225 million
Paleozoic	Permian		270 million
	Pennsylvanian		325 million
	Mississippian		350 million
	Devonian		400 million
	Silurian		440 million
	Ordovician		500 million
	Cambrian		600 million

Source: Webster's Ninth New Collegiate Dictionary, 1991:512 and AEIDC, 1975:37

The Brooks Range consists of east-west trending mountain groups that reach heights in excess of 6000 feet. Rocks of pre-Mississippian age (350 million + years) to Tertiary age (7 million + years) are exposed due to extensive uplift, folding and faulting. There is little to no oil and gas potential in the Brooks Range because of this extensive deformation and uplift, however these pre-Mississippian to Tertiary age rocks are studied by petroleum geologists, because they do contain petroleum where they occur beneath the sale area.

The Arctic Foothills is a narrow province between the Brooks Range and the Arctic Coastal Plain, consisting of a series of rolling hills, mesas, and east-trending ridges that descend from 1,500 to 900 foot elevations. The rocks in this area are less deformed and younger than those to the south.

The Arctic Coastal Plain contains surface sediments which were formed by fluvial (moving water) and deltaic deposition. These sediments are relatively uniform sandy silts (Craig, et al., 1985). The coastal

plain is underlain by the Colville Basin; a large east-west trending foreland basin of Cretaceous (135 million + years) to Tertiary age (7 million + years). The subsurface geology of this area and the history of previous petroleum production and exploration makes it the most prospective area for hydrocarbons in northern Alaska.

The history of rocks beneath the Sale 87 area is marked by periods of continental rifting, mountain building, and sedimentary deposition. This history is marked by four distinct geologic sequences of rocks with each having a unique sediment source area, depositional environment, and structural character. As these major rock sequences were being formed relatively smaller scale events, such as changes in sea level, altered the depositional environment and created additional internal complexities. The four major rock sequences from oldest to youngest (the oldest rocks are the deepest) are: the Franklinian, Ellesmerian, Rift, and the Brookian. The order of events in the evolution of the area geology were (see Figure 2.3);

1. A stable early Arctic Continental Platform before Devonian time,
2. Onset of continental rifting with uplift to the north of this stable Arctic platform and deposition of sediments southward; and
3. Continued rifting, uplift, and termination of deposition from the north, along with uplift of the Brooks Range and deposition of sediments from the south onto the Arctic Coastal Plain.

The oldest rock sequence, the Franklinian, may have once been a stable arctic continental platform before middle Devonian time (about 400 million years ago). This sequence is also referred to as the pre-Mississippian sequence, because of a lack of continuous geologic information. The Franklinian sequence contains a wide range of rock types that include volcanics, granites, carbonates, and metamorphosed argelites. Due to its geology and tectonic history, the Franklinian sequence is considered to have low petroleum potential (Richter, 1997).

During middle to late Devonian time, a mountain building and rifting event uplifted the Franklinian sequence, deforming and metamorphosing the rocks in the process. Sediments from the uplifted Franklinian sequence spread southward into the large arctic basin (epicontinental shelf). This process continued through to late Cretaceous time. These northerly-sourced sediments formed the Ellesmerian Sequence (Moore, et al., 1994).

The Ellesmerian Sequence is the most important geologically in terms of petroleum production. Formations within the Ellesmerian Sequence form the primary petroleum reservoirs at Prudhoe Bay, and Endicott. The Ellesmerian Sequence contains marine carbonates and quartz and chert rich clastic rocks, representing about 150 million years of deposition (Mississippian through Triassic). From the center of the Colville Basin, the Ellesmerian thins to the south due to depositional distance from its source and it thins to the north due to subsequent uplift and erosion (Moore, et al., 1994).

Rifting of the continental mass dominated the geology by the end of the late Jurassic to late Cretaceous periods. The northern continental source for the Ellesmerian sediments supplied less and less sediment to the arctic basin as time passed. Uplift and faulting of the Franklinian and Ellesmerian sequence formed fault blocks and grabens (low areas between fault blocks). These grabens were filled by sediments from the locally uplifted or upfaulted Ellesmerian and Franklinian sequences, forming the Rift Sequence (Craig, et al., 1985). It is also at this time that the Barrow Arch formed along the present day Beaufort Coast. Sedimentation from the north eventually ended sometime in the Late Cretaceous and the following period of non-deposition along with continued uplift along the Barrow Arch created a regional Lower Cretaceous Unconformity (LCU) which becomes angular approaching the Barrow Arch from the south. To the north of the Barrow Arch the Ellesmerian sequence is absent. The LCU is an important migration and accumulation element for most of the oil fields on the North Slope, including Prudhoe Bay (Jamison, et al., 1980).

Figure 2.3 Evoloution of North Slope Geology

To the south, compressional forces in the Jurassic to early Cretaceous caused thrust faulting in what is now the Brooks Range. Sediments from the thrust faulted blocks in the Brooks Range poured into the Colville Basin, progressively filling it from the south, forming the Brookian Sequence. Brookian sediments filled the Colville Basin and spread out over the Barrow Arch and onto Alaska's continental margin during the upper Late Cretaceous through Tertiary time. Petroleum accumulations in the Brookian Sequence are found throughout the North Slope basin, including at West Sak, Schrader Bluff, Flaxman Island, and the Outer Continental Shelf (OCS) accumulation at Hammerhead (Weimer, 1987).

Onshore present day geology of the sale area is, in general, comprised of a thick section of unconsolidated Quaternary sediments (Brown and Kreig 1983), deposited within the last 1 million years. These sediments are probably of the Gubik Formation which unconformably overlies the weakly cemented sediments of the upper Brookian Sequence. Most Quaternary deposits are unconsolidated sand and gravel composed of reworked Brookian sediments, along with materials from the present day Brooks Range. Overlying these deposits are ice-rich silts and sandy silts (1.5 m to 2.5 m thick at Prudhoe Bay) that include variable amounts of organic matter, which are deposited by the numerous rivers on the North Slope. In addition to these fluvial deposits are local areas of eolian deposits (sand dunes) derived from river silts (Brown and Kreig, 1983) For more on surface deposits and soils of the Sale 87 area, see sub-section D.3 of this chapter.

2. Climate

The entire sale area is within the Arctic climate zone of Alaska. Surface conditions in the Arctic vary dramatically from year to year and day to day. In summer, the climate is generally mild. The three-month ice-free season is critical to biological productivity. In contrast, winters are severe, forcing many species to migrate south.

a. Precipitation

Precipitation throughout the sale area varies with location. Heaviest rain and snow falls occur in higher elevations. Along the Beaufort Sea coast, the amount of precipitation is low. Air temperature controls how much moisture the air holds as a vapor. Extremely cold air can contain only very small amounts of water vapor. The result is low precipitation. Therefore, the region is classified as a desert—a desert of frozen land (AEIDC, 1975:18). Most precipitation occurs during summer as rain. Average annual snowfall is only 12 inches along the coast (AEIDC, 1975:18). Average annual snowfall in the eastern Brooks Range is estimated as high as 100 inches, whereas along the northwest coast, it averages 12 inches. Umiat, at the southern boundary of the sale area receives an average of 5.71 inches of precipitation and 33.2 inches of snowfall each year. In contrast, Oliktok Point along the Arctic coast receives an average of 5.39 inches of precipitation and 18.8 inches of snowfall each year (AEIDC, 1975:18). In the Nuiqsut-Prudhoe Bay area, precipitation averages 5 inches with an annual snowfall of 20 inches. Anaktuvuk Pass, located outside of the sale area and deep in the Brook Range receives an average of 10.65 inches of precipitation and 63 inches of snowfall annually (ADCRA, 1996).

b. Temperature

The Arctic receives most of its heat energy during the short summer months. The decrease of heat energy in fall and winter is gradual at southern latitudes, but is dramatically rapid at extreme northern latitudes. Areas of extensive cloud cover receive much less heat energy. The length of the day is also a factor, since longer days produce more radiation. The sun angle in the Arctic is low even during long days. As a result, the sun's rays pass through more atmosphere which absorbs some of the energy before it reaches the surface. Although the Arctic Ocean and Beaufort Sea are frozen for 10 months of the year they have a modifying effect on coastal temperatures. February is the coldest month throughout the Arctic with the exception of Anaktuvuk Pass, where January is coldest. Average minimum temperatures range from -25° F along the coast to minus -35° F along the foothills of the Brooks Range. July is the warmest month with average maximum temperatures in the 40's along the north coast to mid-to-low 60's along the foothills (AEIDC, 1975:15). Throughout a given year, temperatures in the Nuiqsut-Prudhoe Bay area can range from -56 to 78 degrees F. In contrast, the climate of Anaktuvuk Pass has a strong continental influence with temperatures ranging from -14 to 50 degrees (ADCRA, 1996).

c. Winds

A semi-permanent area of high pressure is centered approximately 600 miles north of the Alaska arctic coast. Air continually flows south from this area of higher pressure as a north wind. By the time it reaches the Beaufort Sea coast its direction is between northeast and east because of the rotation of the earth (AEIDC, 1975:19). Wind direction is predominately easterly but shifts to westerly from January to April. Part of this shift is due to piling up of air against the Brooks Range. Sea breezes (air moving inland in response to unequal heating across the coastline) control at least 25 percent of the summer surface wind direction and extend to at least 20 offshore (MMS, 1996: III-A-3)(Kozo, 1984:33).

Surface wind speeds along the coast are persistent and strong compared to those in the south. Coastal wind speeds of 30 to 50 knots are common along the coast during winter months, while calm conditions are more common to the south. Barrow experiences calm winds only one percent of the time, while the winds are calm at Barter Island about four percent of the time, and at Umiat about 17 percent. The average annual wind speed is 10.6 knots at Barrow and 11.5 knots at Barter Island. Wind direction is predominantly easterly along the coast and is divided equally between east and west at Umiat. (AEIDC, 1975:19).

Surface wind conditions affect nearshore currents, the movement of ice floes and oil spills, and the formation and break-up of sea ice. Winds also influence the timing of migratory activity in animals, including arctic fishes, and the relative safety of subsistence harvesting and oil and gas activities in the Arctic (Kozo, 1984). Strong winds produce extensive coastal erosion, and can cause structural damage to buildings. Arctic winds also blow snow and cause whiteout conditions, making surface navigation across the flat, horizon-less coastal plain nearly impossible. Strong winds also severely restrict aircraft travel in the sale area (AEIDC, 19758:19).

3. Hydrology and Soils

The southern half of the sale area lies in the northern foothills of the Brooks mountain range. These foothills are characterized by irregular buttes, knobs, mesas, east-trending ridges, and intervening, rolling tundra plains. Most streams east of the Colville River are braided with large gravel flats. The Arctic coastal plain west of the Colville River is flat with occasional pingos and a section of active and stabilized sand dunes which rise as high as 40 feet above the plain. East of the Colville River, the White Hills and Franklin Bluffs provide some topographic relief above the plain. The combination of extensive flat terrain, and a continuous layer of permafrost beneath a shallow active permafrost layer result in poorly drained soils and marshes throughout the northern portion of the sale area (AEIDC, 1975:56).

a. Soils

Major river corridors of the Colville, Kuparuk, Sagavanirktok, Shaviovik and Canning are underlain by unconsolidated alluvial (stream laid) deposits. These deposits are course-grained, generally well-drained, not frost-susceptible, provide good foundation material, and are relatively easy to excavate. The uplands between these rivers are overlain by coastal plain deposits. These deposits include both course and fine-grained material, and have generally high silt content, especially near the surface. Coastal plain deposits generally are poorly drained, high in ice content, difficult to excavate, and are frost-susceptible making them less suitable for foundation material. In the southern portion of the sale area, Tertiary age bedrock is exposed in the White Hills, Franklin Bluffs, and in the rolling hills to the west of the Canning River. Organic surface material, called peat, is distributed throughout the sale area and provides the bedding to support the tundra mat above. Peat is poorly drained, contains a high content of ice or water, and is commonly removed or filled over prior to construction (AEIDC, 1975:64). Wind-blown silts may form thin layers mixed with or underlying the peat layer (AEIDC, 1975:60).

Permafrost consists of any soil or other superficial deposit, including bedrock, that has been colder that 0° C for two or more years. Permafrost soils may be nearly ice free in coarse, unsaturated materials and may contain more than 50 percent water in finer grain saturated soils. Alaska has two types of permafrost classified as continuous or discontinuous. Continuous permafrost implies that the ground is frozen over nearly all the landscape and is colder than -5° C at the depth below annual seasonal temperature changes (depth varies based on rock type and water content, but is about 15 m). Discontinuous permafrost is ground that is between 0° C and -5° C and as the term suggests, is not continuous. In discontinuous zones of permafrost,

ground on south facing slopes and under large bodies of water are usually not frozen. Generally north of Atigun Pass (crest of the Brooks Range), the permafrost is continuous (Brown and Kreig, 1983). Heading offshore the permafrost becomes progressively more discontinuous (MMS, 1996).

Near Prudhoe Bay, permafrost extends to a depth of about 600 m which is the probable case for most all of the onshore sale area (Brown and Kreig, 1983) (Combellick, 1994, citing to Collett and others 1989). The depth of the active layer, or the layer of seasonal thaw is generally less than 0.9 m and 1.8 m beneath active stream channels. Ice content varies from minor segregated ice to massive ice in the form of ice wedges and pingos. Permafrost, like coastal winds, shallow gas deposits, and earthquakes, are geophysical phenomena which may pose hazards to oil and gas operations (see Chapter VI).

b. Hydrology

The summer season on the Arctic coastal plain is initiated by extensive Spring flooding along the coastal margin. The heaviness of this flooding varies from year to year and depends on factors such as amount of upland snow accumulation and the timing of river ice and sea ice break-up. The speed, direction, and persistence of summer winds determine whether freshwater river runoff accumulates or dissipates in the nearshore waters of the Beaufort Sea. This brief, but heavy seasonal flood breaths life into all habitats of the sale area after a long dormant winter. River deltas are made up of major and minor channels, and numerous oxbows and lakes. These river deltas, especially the Colville, provide important migrating, spawning, feeding and overwintering habitat for arctic fish (see Chapter Three). The river systems of the sale area also provide important habitat for many species of birds, like Peregrine Falcon, and migratory and feeding habitat for caribou, bear, wolf, and foxes. Additionally, subsistence harvesting is heavily dependent on the productivity and species diversity of the rivers, streams, and lakes of the North Slope.

Numerous lakes in the sale area are formed by thermokarst (freeze and thaw) processes. Thermokarst topography consists of mounds, sink holes, tunnels, caverns, short ravines, lake basins, and circular lowlands. Melting of the underlying permafrost creates settling of the soil, resulting in depressional features, such as thaw lakes. On the Arctic coastal plain, thaw lakes are elongated and oriented on a north-northeast axis by prevailing wind patterns. Thaw lakes cover more than half of the total surface area of the plain. In the southern portion of the Sale 87 area, lakes are less oriented and are fewer in quantity.

Across the coastal plain, ground-surface depressions cause pooling of water in summer. This pooling causes the underlying permafrost to melt. Thaw continues along lake margins, extending the lake which may merge with other thaw lakes. Eventually, thaw extension of the lake continues until higher ground is breached and the lake is drained through an outlet channel. Some thaw lakes are connected to river channels while others are not. Drained lakes leave behind a marshy depression surrounded by a ridge of surface material (residual), formerly the lake margin. The initial surface residuals rise 10 to 15 feet above the adjacent drained basins and cover about twenty-five percent of the land surface on the coastal plain (AEIDC, 1975:68).

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